

TABLE 3.—*Solar radiation intensities at Lincoln, Nebr. (State University farm)—Continued.*

[Gram-calories per minute per square centimeter of normal surface.]

Date.	Sun's zenith distance.									
	0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°
	Air mass.									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
1915.	<i>Gr.-</i>	<i>cal.</i>	<i>Gr.-</i>	<i>cal.</i>	<i>Gr.-</i>	<i>cal.</i>	<i>Gr.-</i>	<i>cal.</i>	<i>Gr.-</i>	<i>cal.</i>
Sept. 16.	1.43	1.33	1.24	1.15	1.07	1.00	0.94	0.90	0.87	0.84
18.	1.10	1.10	1.04	0.97	0.91	0.87	0.84	0.81	0.78	0.75
19.	1.10	1.10	1.04	0.97	0.91	0.87	0.84	0.81	0.78	0.75
20.	1.40	1.32	1.24	1.15	1.07	1.00	0.94	0.90	0.87	0.84
21.	1.40	1.28	1.17	1.08	0.99	0.92	0.86	0.81	0.77	0.73
22.	1.27	1.13	1.01	0.91	0.83	0.76	0.69	0.64	0.61	0.58
27.	1.26	1.15	1.05	0.97	0.91	0.84	0.77	0.71	0.67	0.63
29.	1.27	1.13	1.01	0.91	0.83	0.76	0.69	0.64	0.61	0.58
Means.	1.31	1.27	1.15	1.06	0.93	0.88	0.83	0.74	0.69	(0.72)
A. M.										
Oct. 2.	1.22	1.10	1.00	0.92	0.85	0.79	0.74	0.69	0.64	0.61
5.	1.44	1.32	1.21	1.12	1.02	0.94	0.87	0.81	0.77	0.73
7.	1.51	1.44	1.37	1.30	1.23	1.17	1.11	1.04	0.99	0.94
8.	1.51	1.44	1.37	1.30	1.23	1.17	1.11	1.04	0.99	0.94
9.	1.51	1.44	1.37	1.30	1.23	1.17	1.11	1.04	0.99	0.94
10.	1.37	1.32	1.24	1.15	1.07	1.00	0.94	0.90	0.87	0.84
13.	1.34	1.32	1.18	1.08	0.99	0.92	0.86	0.81	0.77	0.73
17.	1.35	1.27	1.19	1.13	1.07	1.00	0.94	0.89	0.84	0.80
18.	1.27	1.19	1.10	1.02	0.94	0.87	0.81	0.77	0.73	0.69
21.	1.29	1.21	1.14	1.06	0.99	0.92	0.86	0.81	0.77	0.73
22.	1.30	1.25	1.18	1.08	0.99	0.92	0.86	0.81	0.77	0.73
23.	1.37	1.30	1.22	1.16	1.09	1.02	0.94	0.87	0.81	0.77
27.	1.35	1.27	1.19	1.13	1.07	1.00	0.94	0.89	0.84	0.80
29.	1.43	1.35	1.27	1.13	1.00	0.94	0.87	0.79	0.73	0.69
Means.	1.36	1.29	1.22	1.16	1.06	0.99	0.91	0.79	0.73	0.69
P. M.										
Oct. 2.	1.22	1.10	1.00	0.92	0.85	0.79	0.74	0.69	0.64	0.61
3.	1.44	1.35	1.27	1.19	1.12	1.05	0.99	0.93	0.88	0.84
5.	1.51	1.42	1.34	1.28	1.21	1.16	1.11	1.06	1.02	0.97
8.	1.51	1.42	1.34	1.28	1.21	1.16	1.11	1.06	1.02	0.97
9.	1.51	1.42	1.34	1.28	1.21	1.16	1.11	1.06	1.02	0.97
13.	1.34	1.23	1.15	1.08	1.01	0.96	0.90	0.82	0.77	0.73
17.	1.35	1.27	1.19	1.13	1.07	1.00	0.94	0.89	0.84	0.80
21.	1.21	1.13	1.06	0.99	0.92	0.85	0.81	0.77	0.73	0.69
22.	1.21	1.12	1.04	0.98	0.93	0.88	0.83	0.79	0.75	0.71
26.	1.22	1.03	0.94	0.88	0.83	0.78	0.73	0.69	0.64	0.61
27.	1.24	1.10	1.01	0.94	0.88	0.83	0.78	0.73	0.69	0.64
29.	1.29	1.20	1.14	1.07	1.00	0.94	0.87	0.79	0.73	0.69
Means.	1.41	1.25	1.15	1.10	1.06	1.00	0.95	0.90	0.85	0.80
A. M.										
Nov. 1.	1.30	1.20	1.11	1.00	0.91	0.85	0.80	0.75	0.71	0.67
8.	1.40	1.30	1.14	1.03	0.96	0.90	0.84	0.79	0.74	0.69
12.	1.40	1.30	1.14	1.03	0.96	0.90	0.84	0.79	0.74	0.69
14.	1.34	1.24	1.15	1.08	1.01	0.96	0.90	0.82	0.77	0.73
21.	1.47	1.41	1.34	1.28	1.23	1.17	1.12	1.07	1.02	0.97
26.	1.43	1.33	1.24	1.16	1.09	1.02	0.94	0.87	0.81	0.77
29.	1.45	1.36	1.30	1.22	1.17	1.12	1.07	1.02	0.97	0.92
Means.	1.44	1.41	1.31	1.22	1.13	1.08	1.00	0.95	0.90	0.85
P. M.										
Nov. 1.	1.30	1.20	1.11	1.00	0.91	0.85	0.80	0.75	0.71	0.67
11.	1.42	1.36	1.23	1.18	1.13	1.07	1.02	0.97	0.92	0.87
12.	1.37	1.29	1.22	1.14	1.07	1.02	0.97	0.92	0.87	0.82
19.	1.43	1.36	1.30	1.25	1.19	1.14	1.09	1.04	0.99	0.94
21.	1.52	1.44	1.37	1.30	1.23	1.17	1.12	1.08	1.03	0.98
26.	1.50	1.29	1.16	1.07	1.01	0.96	0.90	0.84	0.79	0.74
28.	1.49	1.45	1.37	1.31	1.25	1.19	1.14	1.09	1.04	0.99
29.	1.54	1.45	1.37	1.31	1.25	1.19	1.14	1.09	1.04	0.99
Means.	1.45	1.34	1.25	1.18	1.11	1.07	1.02	1.03	0.98	(0.93)
A. M.										
Dec. 4.	1.30	1.23	1.14	1.09	1.02	0.92	0.87	0.82	0.77	0.73
8.	1.41	1.29	1.21	1.13	1.07	1.02	0.97	0.92	0.87	0.82
13.	1.36	1.26	1.17	1.10	1.02	0.94	0.87	0.81	0.77	0.73
17.	1.38	1.31	1.23	1.17	1.10	1.02	0.94	0.87	0.81	0.77
20.	1.42	1.34	1.24	1.13	1.07	1.02	0.97	0.92	0.87	0.82
21.	1.36	1.32	1.24	1.12	1.07	1.02	0.97	0.92	0.87	0.82
28.	1.50	1.41	1.32	1.22	1.17	1.12	1.07	1.02	0.97	0.92
Means.	1.36	1.36	1.29	1.20	1.09	1.02	0.95	0.89	0.84	0.79
P. M.										
Dec. 3.	1.30	1.28	1.17	1.11	1.06	1.00	0.95	0.90	0.85	0.80
4.	1.21	1.10	1.02	0.93	0.87	0.82	0.77	0.72	0.67	0.63
8.	1.35	1.25	1.16	1.09	1.02	0.96	0.90	0.84	0.79	0.74
17.	1.37	1.27	1.18	1.11	1.04	0.98	0.92	0.86	0.81	0.76
21.	1.35	1.29	1.24	1.19	1.14	1.09	1.04	0.99	0.94	0.89
28.	1.35	1.29	1.24	1.19	1.14	1.09	1.04	0.99	0.94	0.89
Means.	1.30	1.24	1.18	1.14	1.15	(1.10)	(0.86)	(0.81)	(0.76)	(0.71)

SOLAR RADIATION MEASUREMENTS AT MADISON, WIS., 1913-1915.

By HERBERT H. KIMBALL, Professor of Meteorology, and ERIC R. MILLER, Local Forecaster.

[Dated: Washington, D. C., Feb. 15, 1916.]

The radiation measurements summarized in Table 3 below are in continuation of those for the period July, 1910, to June, 1912, inclusive, published in the Bulletin of the Mount Weather Observatory, 1912, 5 : 177-181. These latter are included on the monthly means of Table 3, which are the arithmetical means of all the A. M. or P. M. published measurements at the respective air masses for months of the same name.

The means here given are generally lower than those summarized in the Bulletin above referred to, p. 182, Table 2, and especially during the early months of the year. This is no doubt due in part to the marked depression in radiation intensities during the latter part of 1912 and most of 1913, following the eruption of Katmai volcano in Alaska in June, 1912.¹ Undoubtedly, however, the occasions are rare when such high values as those of the early months of 1911 and 1912 will be measured at Madison, since the atmosphere at that place is apt to be more or less smoky, especially during the winter months.

TABLE 1.—*Comparison of radiation intensities measured at different stations with exceptionally clear skies.*

[Gram-calories per minute per square centimeter of normal surface.]

Station.	Date.	Air mass.					
		1.5	2.0	2.5	3.0	3.5	4.0
		<i>Gr.-</i>	<i>Gr.-</i>	<i>Gr.-</i>	<i>Gr.-</i>	<i>Gr.-</i>	<i>Gr.-</i>
		<i>cal.</i>	<i>cal.</i>	<i>cal.</i>	<i>cal.</i>	<i>cal.</i>	<i>cal.</i>
Madison, Wis.	Sept. 4, 1914.	1.37	1.29	1.18	1.08	1.01	0.94
Mount Weather, Va.	Sept. 28, 1914.	1.48	1.40	1.32	1.26	1.20	1.14
Madison, Wis.	Dec. 30, 1914.	1.47	1.37	1.31	1.24	1.18	1.12
Washington, D. C.	Dec. 26, 1914.	1.61	1.42	1.32	1.24	1.18	1.12
Madison, Wis.	Dec. 28, 1915.	1.46	1.40	1.32	1.25	1.18	1.12
Lincoln, Nebr.	do.	1.50	1.40	1.38	1.32	1.26	1.20
Santa Fe, N. Mex.	Dec. 24, 1915.	1.59	1.53	1.43	1.35	1.30	1.25

On December 30, 1914, and December 28, 1915, the highest December radiation intensities of record at Madison were obtained, and on September 4, 1914, the highest September intensities. It is of interest to compare these with intensities at other stations at about the same time, as has been done in Table 1. The intensities measured at Mount Weather, Va., on September 28, 1914, are the highest September intensities ever measured at the station. Likewise, those for Washington on December 26, 1914, are the highest intensities for corresponding air masses measured at Washington in any month. This is also true of the measurements at Lincoln, Nebr., on December 28, 1915, while those obtained at Santa Fe on December 24, 1915, are the highest December radiation intensities yet measured at that station.

Marvin pyrheliometer No. 5, of the spiral-ribbon type, which became the station instrument at Madison on November 24, 1911, has been in continuous use since that date. It was recompared with Smithsonian silver-disk pyrheliometer No. 1 during March and April, 1912, and again in March, 1915. The results are given below in

¹ See Bulletin of the Mount Weather Observatory, 1914, 6 : 208, figure 1, for a graphic presentation of this depression.

Table 2, and do not indicate any change in the constants of the instrument.

TABLE 2.—Comparison of pyrheliometers at Madison, Wis.

Date.	Smithsonian No. 1.	Marvin No. 5.	Ratio: Marvin Smithsonian
1911.			
Nov. 24.....	Gr.-cal. 1.369	Gr.-cal. 1.361	0.994
24.....	1.375	1.380	1.004
1912.			
Mar. 28.....	1.361	1.349	0.991
29.....	1.481	1.509	1.019
29.....	1.519	1.503	0.989
1915.			
Apr. 5.....	1.251	1.243	0.995
5.....	1.282	1.258	0.981
5.....	1.016	1.002	0.986
Mar. 26.....	1.449	1.486	1.026
26.....	1.500	1.529	1.019
27.....	1.383	1.425	1.030
*27.....	1.404	*1.417	1.009
30.....	1.394	1.391	0.998
30.....	1.383	1.372	0.992

*After resooting surface of the Marvin instrument.

For more detailed information relative to exposure of instruments and methods of observation the reader is referred to this number of the REVIEW, page 2.

TABLE 3.—Solar radiation intensities at Madison, Wis., 1913 to 1915, inclusive.

[Gram-calories per minute per square centimeter of normal surface.]

Date.	Sun's zenith distance.										
	0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	78.7°	77.4°	78.7°	79.8°	80.7°
	Air mass.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1913.											
Jan. 8.....	Gr.-cal. 1.20	Gr.-cal. 1.13	Gr.-cal. 1.08	Gr.-cal. 1.01	Gr.-cal. 0.92	Gr.-cal. 0.84	Gr.-cal. 0.76	Gr.-cal. 0.68	Gr.-cal. 0.60	Gr.-cal. 0.52	Gr.-cal. 0.44
24.....	1.22	1.16	1.09	1.01	0.92	0.83	0.77	0.69	0.60	0.52	0.44
28.....	1.23	1.17	1.10	1.02	0.93	0.84	0.78	0.70	0.61	0.53	0.45
29.....	0.99	0.93	0.86	0.78	0.69	0.61	0.54	0.47	0.39	0.32	0.25
1914.											
Jan. 12.....	1.31	1.24	1.16	1.08	0.99	0.90	0.81	0.72	0.63	0.54	0.45
16.....	1.31	1.24	1.16	1.08	0.99	0.90	0.81	0.72	0.63	0.54	0.45
22.....	1.09	1.02	0.94	0.85	0.76	0.67	0.58	0.49	0.40	0.31	0.22
30.....	1.09	1.02	0.94	0.85	0.76	0.67	0.58	0.49	0.40	0.31	0.22
1915.											
Jan. 18.....	1.38	1.28	1.20	1.10	1.00	0.90	0.80	0.70	0.60	0.50	0.40
21.....	1.37	1.27	1.19	1.09	0.99	0.89	0.79	0.69	0.59	0.49	0.39
23.....	1.43	1.35	1.25	1.15	1.05	0.95	0.85	0.75	0.65	0.55	0.45
Means (1911-1915).....	1.33	1.24	1.16	1.06	0.96	0.86	0.76	0.66	0.56	0.46	0.36
P. M. 1913.											
Jan. 8.....	1.07	1.01	0.96	0.89	0.81	0.72	0.63	0.54	0.45	0.36	0.27
24.....	0.97	0.91	0.84	0.76	0.67	0.58	0.49	0.40	0.31	0.22	0.13
25.....	0.84	0.81	0.76	0.69	0.61	0.52	0.43	0.34	0.25	0.16	0.07
28.....	1.13	1.06	0.99	0.90	0.81	0.72	0.63	0.54	0.45	0.36	0.27
1914.											
Jan. 22.....	1.12	1.05	0.97	0.88	0.79	0.69	0.60	0.51	0.42	0.33	0.24
1915.											
Jan. 29.....	1.36	1.31	1.23	1.14	1.04	0.94	0.84	0.74	0.64	0.54	0.44
Means (1911-1915).....	1.31	1.23	1.15	1.05	0.95	0.85	0.75	0.65	0.55	0.45	0.35
A. M. 1913.											
Feb. 1.....	1.27	1.19	1.10	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30
3.....	1.21	1.13	1.04	0.94	0.84	0.74	0.64	0.54	0.44	0.34	0.24
6.....	1.25	1.17	1.08	0.98	0.88	0.78	0.68	0.58	0.48	0.38	0.28
7.....	1.26	1.18	1.09	0.99	0.89	0.79	0.69	0.59	0.49	0.39	0.29
8.....	1.19	1.09	0.99	0.89	0.79	0.69	0.59	0.49	0.39	0.29	0.19
11.....	1.24	1.13	1.03	0.93	0.83	0.73	0.63	0.53	0.43	0.33	0.23
12.....	1.27	1.16	1.06	0.96	0.86	0.76	0.66	0.56	0.46	0.36	0.26
19.....	0.61	0.54	0.47	0.39	0.31	0.22	0.13	0.04	0.00	0.00	0.00
24.....	1.28	1.19	1.08	0.98	0.88	0.78	0.68	0.58	0.48	0.38	0.28
28.....	1.16	1.07	0.97	0.87	0.77	0.67	0.57	0.47	0.37	0.27	0.17

TABLE 3.—Solar radiation intensities at Madison, Wis., 1913 to 1915, inclusive—Continued.

[Gram-calories per minute per square centimeter of normal surface.]

Date.		Sun's zenith distance.										
		0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	78.7°	77.4°	78.7°	79.8°	80.7°
		Air mass.										
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
A. M.		Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.
Feb.	1 st 14.			1.33	1.21	1.07	0.96		0.88	0.86		
	5.....			1.25	1.09	0.99	0.91					
	14.....			1.25	1.09	0.99	0.91					
	16.....		1.47	1.37	1.27	1.17						
	24.....			1.32	1.19		1.05	1.01				
1915.												
Feb.	8.....			1.48	1.37							
	26.....		1.52	1.43	1.31							
	27.....		1.45		1.26	1.18						
Means (1911-1915)			1.50	1.35	1.29	1.20	1.19	1.14	0.97	0.95		
P. M.												
Feb.	1913.											
	1.....				1.15		0.92					
	3.....			1.27	1.16							
	5.....			1.05		1.00						
	7.....			1.21	1.11	1.00						
	8.....					1.03			0.37			
	11.....			1.28	1.14	1.04						
	12.....			1.29	1.24	1.16	1.08					
	24.....			1.18	1.07	0.97						
Feb.	1914.											
	7.....				1.22	1.14	1.03					
	14.....				1.25							
	19.....			1.34	1.16	1.06						
Feb.	1915.											
	6.....			1.38								
	8.....			1.50								
	17.....			1.09								
	26.....			1.45	1.34	1.25	1.17	1.11				
	27.....			1.35	1.26							
Means (1911-1915)				1.36	1.29	1.18	1.14					
A. M.												
Mar.	1913.											
	4.....		1.31	1.25	1.14							
	6.....		1.31	1.16		0.93	0.81					
	16.....							0.72				
	22.....			1.19								
	27.....		1.22	1.03								
	29.....		1.07									
	31.....		1.17	1.04	0.92	0.81						
Mar.	1914.											
	9.....		1.45	1.30	1.21	1.13						
	11.....		1.42	1.27								
	16.....		1.39	1.24			0.98					
	17.....					1.07						
	20.....		1.44	1.32	1.19							
Mar.	1915.											
	1.....		1.40	1.23	1.13				0.91	0.87		
	8.....		1.48	1.36	1.27		1.11	1.04				
	16.....		1.47	1.35	1.22							
	23.....		1.43	1.35				1.06				
	26.....		1.50	1.44				1.14	1.09			
	27.....		1.43	1.35								
	29.....							1.01				
	30.....		1.41	1.32			1.09	1.00				
	31.....			1.36	1.28		1.11	1.03				
Means (1911-1915)			1.43	1.33	1.26	1.20	1.12	1.05	1.04	0.94		
P. M.												
Mar.	1913.											
	4.....		1.32	1.25	1.14							
	8.....			1.27	1.14							
	11.....		1.24	1.12								
	28.....		1.07									
	29.....		1.02									
Mar.	1914.											
	11.....		1.45	1.33								
	14.....			1.20								
	20.....		1.36									
Mar.	1915.											
	16.....		1.48									
	26.....		1.51		1.28	1.18						
	30.....		1.46	1.36				0.97				
Means (1911-1915)			1.39	1.34	1.26	1.21		1.06				

TABLE 3.—Solar radiation intensities at Madison, Wis., 1913 to 1915, inclusive—Continued.

[Gram-calories per minute per square centimeter of normal surface.]

Date.	Sun's zenith distance.										
	0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	78.7°	77.4°	78.7°	79.5°	80.7°
	Air mass.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
P. M.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.
Aug. 18.		1.18				0.83					
19.		1.25	1.12			0.85	0.75				
30.		1.11									
Means (1910-1915)		1.12	0.99	0.86	0.75	0.67	0.70	0.58	0.48		
A. M.											
1912.											
Sept. 25.		1.03	0.89	0.77	0.69						
30.			0.93		0.73						
1913.											
Sept. 4.		1.01		0.84							
9.		1.25	1.13	1.04							
12.		1.28	1.24		1.00						
13.		1.23									
26.		1.23	1.20	1.03							
27.		1.25					0.82				
1914.											
Sept. 2.		1.27			0.98						
3.		1.29			1.08						
4.		1.37	1.29	1.18	1.03						
8.				0.85							
21.						1.00					
24.		1.35	1.24								
1915.											
Sept. 21.		1.39	1.22	1.17	1.13						
22.		1.27	1.16		1.04	0.98					
Means (1910-1915)	1.35	1.24	1.08	1.12	0.96	0.91	0.85	0.80			
P. M.											
1912.											
Sept. 26.		1.01		0.65		0.42					
30.		1.15	1.02								
1913.											
Sept. 4.		0.98		0.73							
9.		1.24	1.10								
10.		1.05	0.95								
12.		1.27		1.07							
26.		1.22		1.09							
1914.											
Sept. 4.		1.29									
18.		1.12									
Means (1910-1915)		1.19	1.08	0.98	0.95	0.72	0.76	0.74			
A. M.											
1912.											
Oct. 1.		0.98	0.92	0.88	0.79	0.70	0.63	0.59			
4.		1.20	1.09	0.95	0.88	0.82	0.74	0.70			
5.		1.03	0.94	0.82	0.69	0.61	0.55	0.49			
7.		1.18									
12.		1.17									
13.		0.99	0.88	0.79				0.54	0.56		
14.			1.10		0.90	0.80		0.65	0.60		
15.		1.21	1.06					0.70	0.65		
16.			1.03				0.65	0.58	0.52		
17.		1.15	0.98				0.57	0.49			
19.		1.20	1.00				0.55	0.51	0.48	0.44	
23.		1.35	1.23					0.81	0.75		
26.		1.33	1.17	1.04	0.94			0.82	0.77		
1913.											
Oct. 1.		0.98	0.87								
2.		1.31		1.13							
3.			1.19				0.80				
13.		1.17			1.03			0.79			
18.		1.30	1.18	1.07							
23.		1.15	1.03	0.92							
24.		1.21	1.08	0.97	0.87						
31.			1.22	1.16	1.00	0.92	0.86	0.79			
1914.											
Oct. 27.							1.04				
30.			1.23				1.00				
31.			1.18	1.08		0.95					
1915.											
Oct. 9.					1.20			0.99			
21.			1.21								
29.				1.17							
Means (1910-1915)		1.31	1.13	1.06	0.98	0.89	0.81	0.69	0.64	0.44	

TABLE 3.—Solar radiation intensities at Madison, Wis., 1913 to 1915, inclusive—Continued.

[Gram-calories per minute per square centimeter of normal surface.]

Date.		Sun's zenith distance.										
		0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	78.7°	77.4°	78.7°	79.8°	80.7°
		Air mass.										
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
P. M. 1912.		Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.	Gr.- cal.
Oct.	4.			1.08	0.95		0.77					
	5.			0.85				0.67				
	7.			1.04	0.92	0.82						
	12.			1.04								
	14.			1.07		0.81				0.51		
	15.									0.57	0.54	
	16.			1.07								
	17.			0.98					0.52	0.45		
	18.				0.88							
	19.			1.14	1.08	1.02						
	23.					0.91						
	26.			1.15	1.03	0.91						
	29.			1.01	0.94							
	1913.											
Oct.	2.				1.11							
	3.					0.88						
	18.			1.17								
	24.			1.18								
	31.					0.96						
	1914.											
Oct.	30.				1.22		1.06					
	1915.											
Oct.	28.				1.27							
	Means (1910-1915)				1.13	1.09	0.98	0.97	0.82	0.80	0.54	0.52
	A. M. 1912.											
Nov.	2.					0.60				0.55		
	8.				0.84			0.56				
	14.				0.98						0.48	
	15.			1.21	1.08	0.95						
	18.			1.10						0.68	0.61	
	19.							0.79		0.70		
	21.				1.27	1.07				0.81	0.76	
	1913.											
Nov.	1.			1.19	1.12	1.05			0.85			
	4.					1.12						
	11.				1.17	1.11			0.95			
	13.									0.77		
	23.			1.30	1.19	1.11			0.96			
	24.				1.27	1.22			1.11			
	1914.											
Nov.	10.			1.38	1.26							
	21.							1.02				
	1915.											
Nov.	2.					1.20				1.00		
	8.				1.20							
	Means (1910-1915)				1.30	1.20	1.12	1.21	1.03	0.97	0.80	0.45
	P. M. 1912.											
Nov.	14.				1.05	0.95						
	15.				1.10	1.00	0.91					
	16.						0.69		0.42			
	21.					1.07						
	1913.											
Nov.	21.								0.54			
	1914.											
Nov.	10.				1.29							
	21.				1.22							
	Means (1910-1915)				1.25	1.17	0.93		0.48			
	A. M. 1912.											
Dec.	9.				1.12	1.03					0.72	
	21.				0.93	0.85	0.82			0.59	0.54	
	22.				0.92							
	28.				1.23	1.13	1.03				0.82	
	1913.											
Dec.	4.				1.16	1.05				0.78	0.72	
	11.				1.20		1.07		0.94	0.88		
	17.					1.12						
	18.					1.16			0.98			
	1914.											
Dec.	11.				1.29	1.17				0.94		
	16.				1.13							
	21.							1.14				
	30.				1.47	1.37						

TABLE 2.—Solar radiation intensities at Madison, Wis., 1913 to 1915, inclusive—Concluded.

(Gram-calories per minute per square centimeter of normal surface.)

Date.	Sun's zenith distance.										
	0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°
	Air mass.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
A. M.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.	Gr-cal.
Dec. 2, 1915.								1.08			
14.				1.37							
28.				1.40	1.39	1.32	1.25			0.99	
Means (1910-1915)				1.25	1.17	1.11	1.15	1.04	0.85	0.68	
P. M.											
Dec. 21, 1912.					0.83	0.76	0.70				
22.					0.83	0.70					
28.					1.01						
1913.								1.01			
Dec. 11.											
1914.					1.21	1.16					
Dec. 11.						1.12					
19.						1.31					
30.											
1915.					1.29						
Dec. 13.					1.40	1.32	1.25				
28.											
Means (1910-1915)					1.23	1.10	0.93				

DURATION OF TWILIGHT.¹

By twilight we mean the light experienced after sunset and before sunrise, and due to the reflection, diffraction, or diffusion of sunlight by the gas molecules, the water particles, and the dust of the atmosphere. The greater the distance of the sun below the horizon the higher and less dense are the atmospheric layers from which the light is received at the shaded surface of the earth. Observation has shown that under the most favorable atmospheric conditions the last trace of twilight disappears when the sun is from 16° to 18° below the horizon, indicating that above a height of 40 to 50 miles, or 60 to 80 kilometers, the air is too rare to reflect or diffuse an appreciable amount of sunlight.

The duration of twilight may be computed from the equation:

$$\cos h = \frac{\sin a - \sin \phi \sin \delta}{\cos \phi \cos \delta},$$

where a is the sun's altitude, considered minus below the horizon, δ is the solar declination or distance from the celestial equator, ϕ is the latitude of the place of observation, and h is the sun's hour angle from the meridian.

From the above equation it will be found that at the equator, at the time of the equinoxes, when the apparent path of the sun is along the prime vertical, it takes the sun 1 hour and 12 minutes to pass from the horizon to a point 18° below it, or vice versa. At the solstices, when the sun appears to describe a small circle about the earth's axis 23½° from the prime vertical, the time is 1 hour and 19 minutes. At latitude 49°, or the latitude of the northern boundary of the United States, where the sun's

apparent path is inclined 49° to the plane of the prime vertical, at the equinoxes it takes 1 hour and 52 minutes for the sun to pass from the horizon to a point 18° below. At the time of the winter solstice it takes 2 hours and 3 minutes, while at the time of the summer solstice the sun does not reach 18° below the horizon. In fact, there is a period of 22 days, from June 10 to July 2, inclusive, during which on the clearest nights the twilight may continue from sunset to sunrise.

Soon after sunset on very clear evenings there frequently appears in the western sky a rosy or purple glow, in the form of an arc about 20° to 25° in diameter with the sun at its center. It disappears when the sun is about 6° below the horizon, indicating that it comes from atmospheric layers not more than 5 or 6 miles (8 to 10 kilometers) above the surface of the earth. It is in these layers that convective action principally occurs, and they are therefore the dusty layers, as well as the layers that contain most of the atmospheric moisture. The purple glow is attributed to the diffraction of light by the dust and water particles in these layers. During the day the same process produces the whitish glow that is seen about the sun in clear weather.

With the disappearance of this glow the intensity of twilight becomes insufficient for the continuance of outdoor occupations. Hence it is the duration of this portion of the twilight, which Europeans term *civil twilight*, that is of practical interest and especially to those engaged in pursuits having to do with transportation, or any other line of out-door work that requires artificial lighting after nightfall, either for illumination or for signal purposes.

The intensity of twilight is not entirely dependent upon the position of the sun, however. The state of the sky is a modifying factor. Clouds on the western horizon, or a hazy condition of the atmosphere that may be due to either dust or moisture, noticeably diminish the twilight intensity, and in the case of very dense clouds may almost completely obliterate it. It is believed, however, that Table 1, which gives the duration of civil twilight or the time required for the sun to pass from the horizon to a point 6° below or vice versa, will be found useful to Weather Bureau officials and others. But it must be understood that the duration as given applies to clear sky conditions only and is too long for cloudy or hazy conditions. Furthermore, high mountains and buildings, or any objects that obstruct the horizon near where the sun rises or sets, will diminish the duration of twilight. It will be noted that at the Equator civil twilight only varies in duration from 24 minutes at the equinoxes to 26 minutes at the solstices, while at latitude 48°, near the northern boundary of the United States, it varies in duration from 36 minutes at the equinoxes to 43 minutes at the winter solstice and 48 minutes at the summer solstice. At Cleveland the variation is from 32 minutes at the equinoxes to 37 minutes at the winter solstice and 39 minutes at the summer solstice.

Table 1 gives the difference between the time when the center of the sun reaches the true horizon and the time it reaches a point 6° below, or vice versa. Without material error, we may add this interval to the time of sunset given in the Weather Bureau Sunshine Tables, or subtract it from the time of sunrise, to obtain the time of ending of civil twilight in the evening or its beginning in the morning. The time thus determined will be that at which the upper limb of the sun is 6° lower than it was at the time it appeared to rise or set on a true horizon, assuming normal atmospheric refraction, and mean solar diameter.

¹ Reprinted from the paper "Daylight illumination and the intensity and duration of twilight," by H. H. Kimball, Ph. D., presented to the Pittsburgh Section of the Illuminating Engineering Society, Cleveland, Ohio, Feb. 18, 1916, and printed by the society in its Transactions.